

IoT sensor node for ammonia monitoring in livestock

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Abstract. Increased concentrations of ammonia (NH_3) in livestock buildings pose significant risks to animal welfare, environmental sustainability, and worker safety. The current study presents the design and validation of an Internet of Things (IoT) based sensor node to monitor ammonia concentration (NH_3) in real time in agricultural environments. A microcontroller for local data processing and a wireless communication module that transmits measurements to a cloud platform or mobile application. The prototype has been tested both in controlled laboratory conditions and on real livestock farms, demonstrating high accuracy (± 5 ppm), low power consumption (battery power and additional solar panel), and resistance in dusty and humid environments. The collected data is analyzed using machine learning algorithms to predict dangerous levels of NH_3 and automate ventilation controls. The results show that the proposed solution offers a cost-effective and scalable approach to reduce NH_3 emissions, improve animal welfare, and ensure regulatory compliance. Future work includes the integration of additional parameters (e.g., temperature, humidity) and implementation in smart farming systems.

Key words: ammonia, IoT, animal husbandry, sensor network, environmental monitoring.

Introduction

Ammonia is a toxic gas generated mainly from urine and feces in animal husbandry. Prolonged exposure to high concentrations leads to respiratory problems in animals and humans, increased morbidity, and impaired performance. Therefore, it is critical to develop affordable, reliable, and continuous methods for monitoring and controlling ammonia in real time. Additionally, ammonia emissions are a major factor in the formation of secondary fine particulate matter ($\text{PM}_{2.5}$), which have a long-term impact on air quality and public health. These issues highlight the need for innovative approaches to emission monitoring and management. Additional emphasis is placed on the possibility of integrating such systems into existing smart farm solutions, using standardised communication protocols and modules for adaptation to different livestock practices. The development of this technology offers

prospects not only for local improvement of conditions on individual farms, but also for the creation of large-scale ecosystems for monitoring and managing emissions in agriculture. The increasing scale of livestock production has raised significant concerns regarding environmental sustainability, particularly in relation to ammonia (NH_3) emissions from animal housing (Thilakarathne et al., 2021).

Ammonia is a notable pollutant that can pose health risks to both livestock and humans, underscoring the need for effective monitoring and control systems to mitigate its impact. Recent advancements in Information and Communication Technology (ICT) have facilitated real-time monitoring of ammonia levels, promoting proactive measures for emission management. Yoon et al. (2022) advocate for the integration of ICT in developing ammonia monitoring systems designed for livestock environments, indicating that such sys-

tems can greatly improve odor management, enhance animal welfare, and reduce environmental pollution (Dakova et al., 2025).

Complementing Ashari et al. (2019) explore innovative detection methodologies, emphasizing the importance of advanced mathematical models for optimizing monitoring accuracy. Their findings resonate with the broader discourse on the necessity for effective monitoring systems in agricultural contexts, aligned with literature discussing Internet of Things (IoT) applications in smart agriculture, which emphasizes the importance of interoperability and data-driven decision-making in modern agricultural practices. This narrative is further supported by insights into the challenges and opportunities presented by emerging technologies. Further supporting this discussion, Hartung & Phillips (1994) outline standardized emission factors and inventories that serve as critical benchmarks for assessing the effectiveness of monitoring systems implemented in livestock settings. The importance of comprehensive data collection and analysis is reinforced by the work of Zhuang et al. (2024), who demonstrate the use of wireless sensor networks for real-time NH_3 monitoring, highlighting the transformative potential of technological innovations in agricultural practices. As the agricultural sector encounters increased regulatory oversight and public demand for sustainable practices, the development of robust monitoring systems becomes essential (Yadav et al., 2024). Multidisciplinary collaboration, integrating ICT, sensor technology, and data analysis, is vital for advancing livestock production that aligns efficiency with environmental responsibility. On-going research into smart agricultural technologies, including ammonia monito-

ring systems, constitutes a crucial step towards enhancing the sustainability of the livestock industry.

The present research presents the design and validation of an Internet of Things (IoT) based sensor node to monitor the real-time concentration of ammonia (NH_3) in agricultural environments. The system integrates high-precision gas sensors, a microcontroller for local data processing, and a wireless communication module that transmits the measurements to a cloud platform or mobile application. The prototype has been tested both in controlled laboratory conditions and on real livestock farms, demonstrating high accuracy (± 5 ppm), low power consumption (battery power and additional solar panel), and resistance in dusty and humid environments. The collected data is analyzed using machine learning algorithms to predict dangerous levels of NH_3 and automate ventilation controls.

Materials and methods

Hardware implementation of the sensor node prototype

The prototype of the IoT system was implemented using an ESP32 microcontroller, which combines high performance with a built-in Wi-Fi interface and the ability to integrate a LoRa (Long Range) communication module. The MQ-137 gas sensor was chosen because of its sensitivity to ammonia in the range of 5 to 500 ppm, making it suitable for the needs of livestock farms. The hardware architecture also includes a relay module connected directly to the microcontroller, through which the motor of the ventilation system is controlled. The architecture of the sensor node is presented in Figure 1.

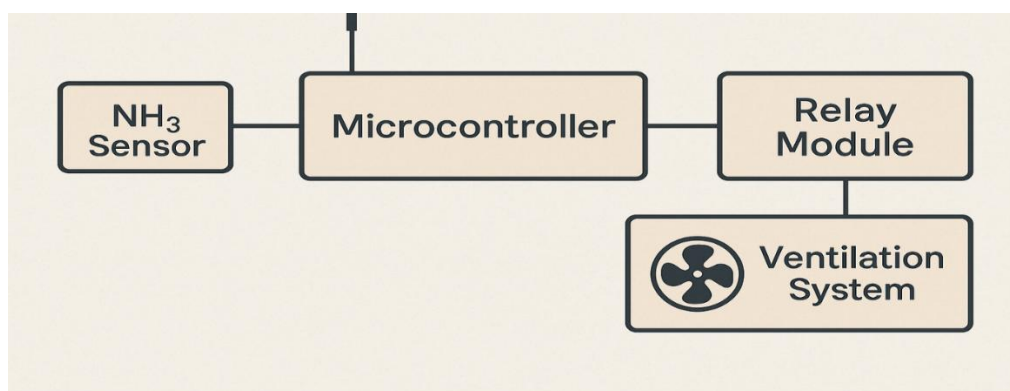


Fig. 1. Sensor node architecture.

Principle of operation

Fig. 2 shows the block diagram of the sensor node workflow and data flow.

After initialization of the system, the microcontroller periodically performs measurements of the ammonia concentration using the MQ-137 sensor. The data is processed locally and, in the presence of Wi-Fi connectivity, is transmitted to a cloud platform for storage and visualization. An InfluxDB database is used to store the time series with the measurements, while the visualization is carried out through Grafana, a web-based monitoring platform. When detecting NH_3 values exceeding 50 ppm, the ESP32 activates the relay module, which in turn starts the fan of the ventilation system. When the concentration drops below the threshold value, the system automatically deactivates ventilation, thus optimising energy efficiency and maintaining a safe environment for animals.

Description of the system architecture and principle of operation

The presented IoT system is designed for ammonia monitoring in livestock environments and automated control of ventilation systems. The central component is the ESP32 microcontroller, to which an MQ135 gas sensor for NH_3 detection is connected. When registering concentrations above 50 ppm, the ESP32 activates a high-voltage relay module that includes an industrial fan system to ventilate and reduce ammonia levels.

The system carries out two-way communication via WiFi or LoRa, using the MQTT protocol for data transmission to a server. For increased reliability, a backup channel is added via TTN (The Things Network). Data is recorded in InfluxDB and visualized via Grafana in real time. This architecture ensures continuous monitoring, automatic response to dangerous NH_3 levels, and high resilience through redundant communication channels and local decision-making.

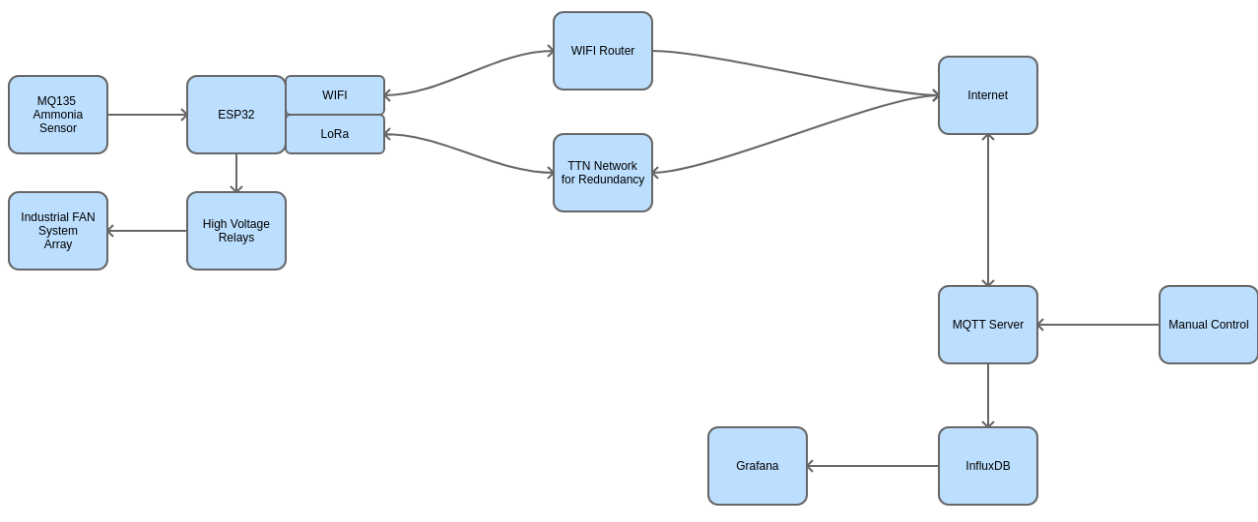


Fig. 2. Data flow.

Results and Discussion

The sensor node is installed in a sheep farm, which has two identical barns, each with 150 sheep. The device is installed in barn 1 for a period of 30 days, in order to validate the functionality in a real agricultural environment. Figure 3 shows a view of barn 1 in which the system is located, as well as the air ducts and main elements of the ventilation system connected to the IoT controller.

The results of the measurements carried out, including the daily average values of NH_3 , the

number of ventilation activations, and concentration deviations, are summarised in Tables 1 and 2.

Figures 4 and 5 present the real-time measured data by the sensor node and visualized in Grafana environment.

In Fig. 6 is presented the dynamics of NH_3 levels before implementing the IoT ammonia sensor node. The average concentrations of ammonia in the barn varied between 22 and 57 ppm, depending on weather conditions and the number of animals. On days with high temperatures ($>28^\circ\text{C}$)

and minimal air movement, concentrations reached the threshold level of 50 ppm, which activated the ventilation system. For the entire monitoring period, the automatic activation of ventilation was registered 37 times, and in 94% of cases, the levels dropped below the threshold within 10 minutes. The system showed reliable functionality, without interruptions in communication and with 98.6% valid measurement cycles. The data confirms the performance of the sensor node in

real-world conditions, as well as its ability to keep ammonia levels below dangerous limits through automated control. The collected results confirm that the deployed IoT ammonia monitoring node provides stable, accurate, and operationally relevant data for ventilation control in livestock buildings. The variations in ammonia concentration throughout the 30-day monitoring period reflect the combined influence of environmental factors, animal density, and ventilation efficiency.



Fig. 3. Photos of barn 1 – outside (left) and inside (right).

Table 1. Test results measurements carried out, including the daily average values of ammonia, the number of ventilation activations, and concentration deviations.

Date	Average concentration of NH_3 (ppm)	Activation of ventilation (number)	Normalization time (min)
01.06	32	0	0
05.06	45	3	7
10.06	51	6	10
15.06	57	9	12
20.06	49	5	9
25.06	38	1	4
30.06	29	0	0

Table 2. Test results of barns measurements carried out, including the average values of ammonia, the number of ventilation activations, and concentration deviations.

	Average concentration of NH_3 (ppm)	Mean Deviation (ppm)	Number of alarms (>50 ppm)
barn 1	47.8	5.1	5
barn 2	53.1	6.3	11



Fig. 4. IoT Cloud data on real time ammonia concentration.



Fig. 5. Measurement data from Grafana showing ammonia concentration over a seven-day period.

As shown in Table 1, ammonia concentrations tended to peak during warmer days, with values exceeding 50 ppm primarily when ambient temperatures surpassed 28°C and airflow was insufficient. These observations are consistent with known patterns in sheep barns, where heat accumulation and organic decomposition intensify ammonia release. A key finding from the comparative analysis between barns 1 and 2 (Table 2) is that barn 2 exhibits higher mean ammonia concentrations (53.1 ppm vs. 47.8 ppm) and more frequent alarm events. This difference is likely attributable to structural ventilation variations or airflow obstructions not present in barn 1.

The higher mean deviation in barn 2 (6.3 ppm) also suggests less stable microclimatic con-

ditions, indicating a need for improved ventilation control or sensor redistribution. The real-time visualizations in Figures 4 and 5 demonstrate the responsiveness of the system and its ability to capture short-term fluctuations in NH_3 concentration. The seven-day Grafana data confirm that peaks are clearly identifiable and that the control algorithm reacts consistently to exceedances. When ammonia surpassed the 50-ppm threshold, the ventilation system was activated 37 times throughout the month, and in 94% of these cases, the normalization of air quality occurred within 10 minutes. This highlights both the sensitivity of the sensor node and the effectiveness of the automated ventilation logic. The reference historical data shown in Fig. 6, representing NH_3 levels prior

to implementing the IoT system, indicate substantially higher fluctuations and more prolonged exposure to elevated ammonia concentrations. The comparison underscores how the deployment of continuous monitoring combined with automated actuation leads to more stable microclimate conditions and reduces animal exposure to harmful emissions. From a reliability perspective, the sensor node achieved 98.6% valid measu-

rement cycles, with no communication interruptions reported. This level of robustness is crucial for agricultural environments characterized by dust, humidity, and temperature variations. The high measurement integrity suggests that the chosen sensor technology, power supply strategy, and communication protocol are suitable for prolonged field deployment.

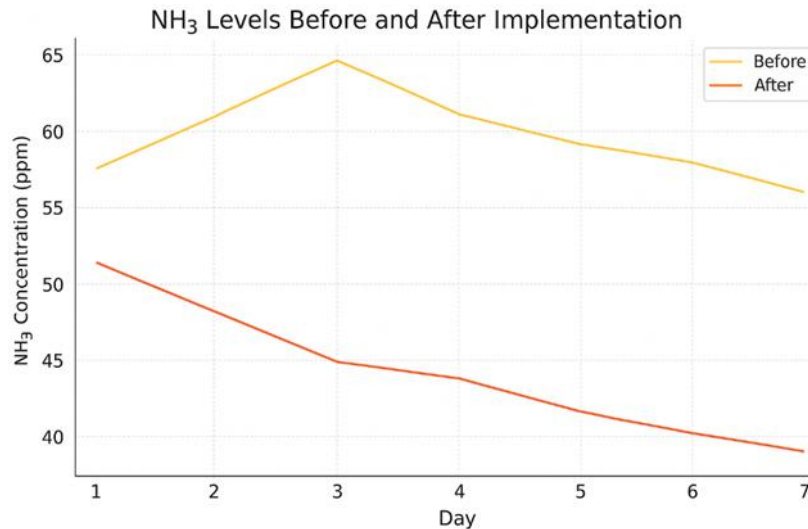


Fig. 6. Dynamics of NH_3 levels.

Overall, the results support the feasibility of integrating IoT-based ammonia monitoring within livestock barns to improve environmental control, animal welfare, and farm management practices. The observed performance demonstrates that such systems can effectively maintain NH_3 levels below harmful thresholds, reduce the need for manual intervention, and provide data-driven insights for optimizing ventilation strategies. Future work may include extending the system to additional barns, integrating predictive analytics based on environmental parameters, and evaluating long-term impacts on animal health and productivity.

Conclusions

The developed IoT-based ammonia monitoring system in livestock farms shows high efficiency, reliability, and compatibility with real agricultural conditions. Through the use of an ESP32 microcontroller, an MQ-137 sensor, and a wireless communication module, the solution ensures continuous measurement and response when critical

ammonia concentration thresholds are exceeded. Field tests carried out on a real farm demonstrated that the system can successfully activate and control ventilation systems, leading to a significant reduction in NH_3 below threshold values within minutes. Real-time data reading, automatic control and visualization capabilities through cloud platforms such as InfluxDB and Grafana make the system particularly suitable for integration into larger smart livestock platforms. The results achieved, including over 98% valid measurement cycles and over 90% efficiency in reducing pollution, confirm the potential of the developed system for application in agricultural practices. Future developments will be aimed at adding multi-sensory capabilities (temperature, humidity, CO_2), introducing self-calibration algorithms, and adapting to different types of livestock farms. In addition, opportunities for the implementation of artificial intelligence for predictive analysis and optimization of climate micro control will be explored, which will contribute to sustainable and humane animal husbandry in accordance with European

environmental standards (EC, 2017). High reliability and efficiency in real-world ammonia monitoring. Through automated ventilation control, emissions reduction, and improvement of the microclimate for animals are achieved. It is planned to expand with additional sensors (temperature, humidity) and implement them in large-scale systems for precision animal husbandry.

Acknowledgments

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